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Fiber Optic Safeguards Sealing System

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
The Harry Diamond Laboratories continued development work on a tamper-resistant/tamper-indicating safing system for the U.S. Arms Control and Disarmament Agency. The safing system consists of a fiber optic seal and related equipment that assembles, photographs, and identifies the seals in the field. The seals are intended for field use in international safeguards and arms control applications.

The report describes improvements in the fiber optic seal assemblies and in the inspection equipment. The inspection equipment includes a means for seal identification by reticle pattern projection that does not require any photographs to be taken of the seal's fingerprints. Also included are (1) the results of the preliminary environmental tests on the sealing system, and (2) detailed operating procedures for the new fiber optic seal assembly and inspection kits.

CONTENTS

FIGURES

1. INTRODUCTION AND DESCRIPTION

The fiber optic sealing system described herein was developed by the Harry Diamond Laboratories (HDL) for the U.S. Arms Control and Disarmament Agency (ACDA) for field use in international safeguards and arms control applications.

Since its conception,[1] the sealing (safing) system has undergone extensive modification[2-4] designed to make it suitable for operational use in the field. The present safing system provides a tamper-resistant/tamper-indicating seal that is designed to meet the needs of the present and projected safeguards activities. The requirements on the seals are that they be (1) uniquely and nondestructively identifiable in the field, (2) easily adaptable to a variety of situations, (3) simple to install, and (4) relatively inexpensive to produce.

The safing system consists of a fiber optic seal (fig. 1) that is assembled in its field location and inspection equipment (fig. 2) for identifying the seal and for indicating whether the seal has been tampered with.

Each seal comprises a fiber optic bundle that is looped around or through the item to be sealed. The fibers from the two ends of the bundle are then intermixed and secured in a common collar (fig. 3). When light is directed onto the fiber ends in one-half of the collar opening, the fiber ends in the opposite half of the collar opening form a unique fingerprint. A 30-times enlargement of the fingerprints (fig. 4) can be viewed through the hand-held viewer provided with the sealing system. A camera attachment (fig. 2) to the hand-held viewer allows this view to be photographed.

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[1] *Lorin R. Stieff and Robert G. Hogan, A Progress Report on the Development of a Tamper Resistant Safing System for International Safeguards and Arms Control Applications, IAEA Symposium on Progress in Safeguards Techniques IAEA/SM-133/113 (July 1970).*

[2] *R. R. Ulrich, Fiber Optic Seals: A Portable System for Field Use in International Safeguards and Arms Control Applications, Harry Diamond Laboratories TR-1571 (October 1971).*

[3] *R. R. Ulrich, Fiber Optic Seals: Improved Seal Assemblies and Inspection Equipment for Field Use in International Safeguards and Arms Control Applications, Harry Diamond Laboratories TR-1669 (July 1974).*

[4] *R. R. Ulrich, Fiber Optic Seals: Glass and Plastic Fiber Optic Safing Systems for International Safeguards and Arms Control Applications, Harry Diamond Laboratories TR-1729 (November 1975).*

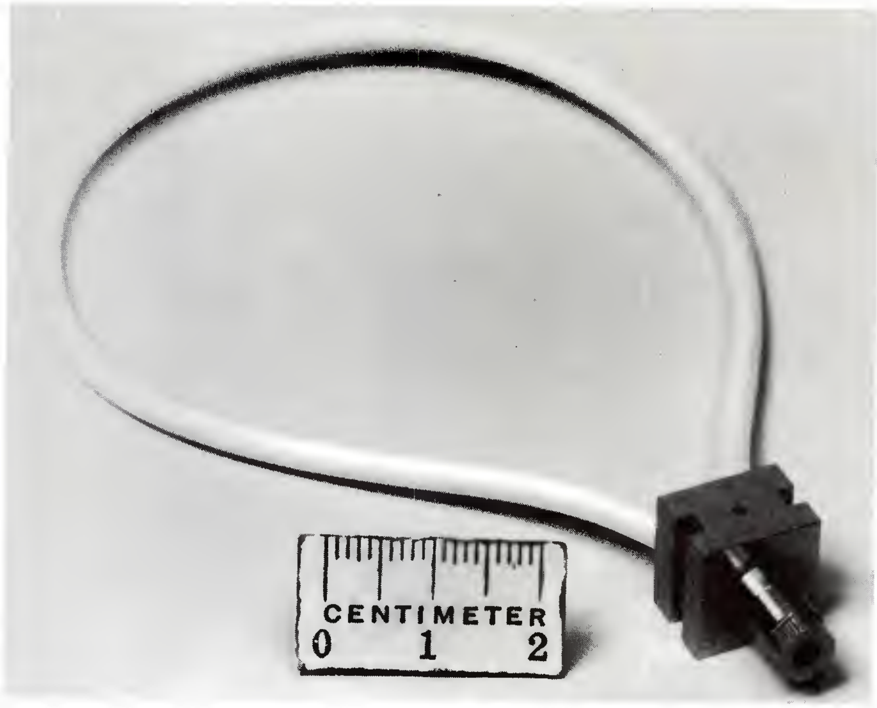

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Figure 1. Fiber optic seal.

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Figure 2. Fiber optic seal inspection equipment.

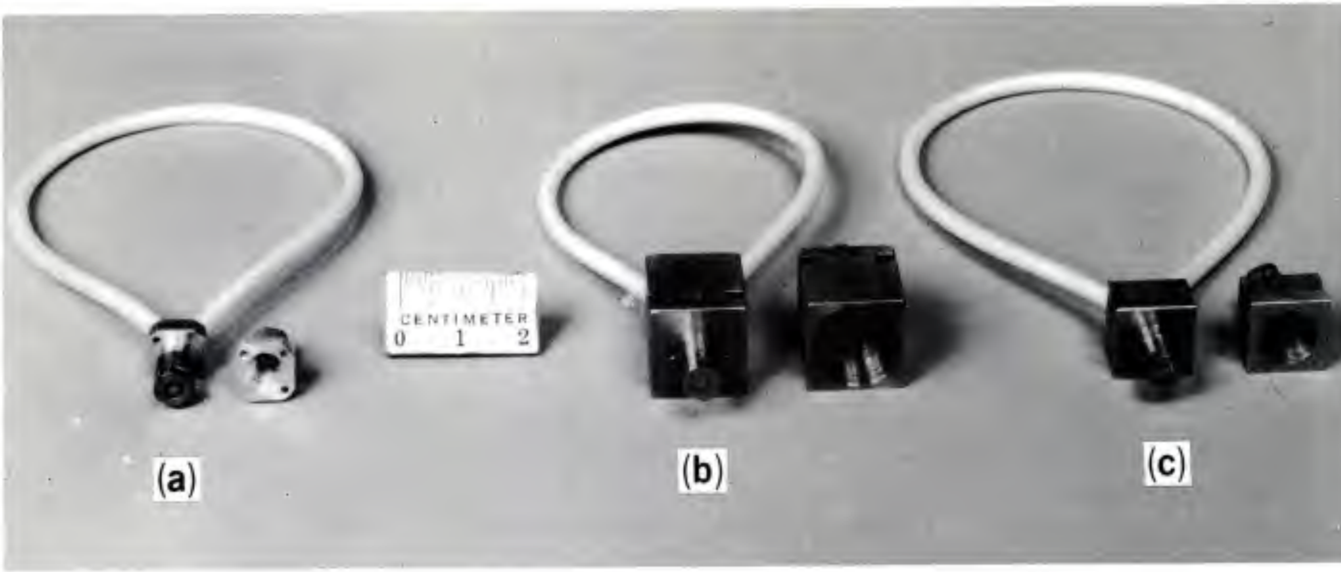

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Figure 3. Fiber optic seals with various collar designs: collar (c) allows fibers to be inserted more readily than with compact collar (a) and allows fibers to be more readily grasped and kept intermixed than with collar (b).

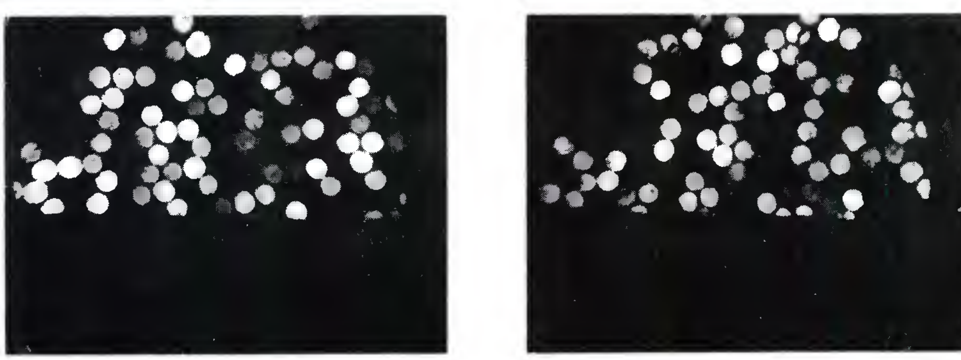

Figure 4. Fiber optic seal fingerprints: seal's fiber optic bundle consists of 180 plastic fibers of 125-μm nominal diam.

Normally, upon installation of a seal, positive and negative prints of the seal fingerprints are taken. For subsequent inspection of the seal, the positive print is compared with the seal fingerprint as seen through the hand-held viewer. The original negative print is used as an overlay on subsequently taken positive prints on the seal. Exact matching of the overlay with the subsequently taken positive print identifies the seal and indicates that it has not been opened or tampered with.

The operation of the fiber optic sealing system requires (1) seal assembly, (2) seal viewing and photographing, (3) seal identification, verification, and integrity check, and (4) seal removal and disposal. These operations are described in detail in appendix A.

In addition to the photographic method of seal identification, verification, and integrity check, the sealing system has provisions for accomplishing these tasks by a reticle pattern projection method described in section 2. The reticle pattern projection method requires no photography and identifies individual fiber ends by their position coordinates in the viewing field.

The effects of certain environmental factors on the fiber optic sealing system also have been investigated. The results of temperature and water submersion tests on the seals are presented in section 3.

2. SEAL IDENTIFICATION BY RETICLE PATTERN PROJECTION

The fiber optic safeguards sealing system kits (developed for ACDA in FY76) included two reticles that, when inserted into the hand-held viewer (fig. 5), provide a means of seal identification that does not require photographing of the seal fingerprint. The first reticle is placed at the focal plane of the eyepiece lens and projects an r, θ coordinate system onto the seal fingerprint as depicted in figure 6. Side lighting of the eyepiece reticle is accomplished by means of a fiber optic bundle that directs light onto it from the viewer lamp bulb.

Figure 5. Hand-held viewer showing reticle controls. 0595-76

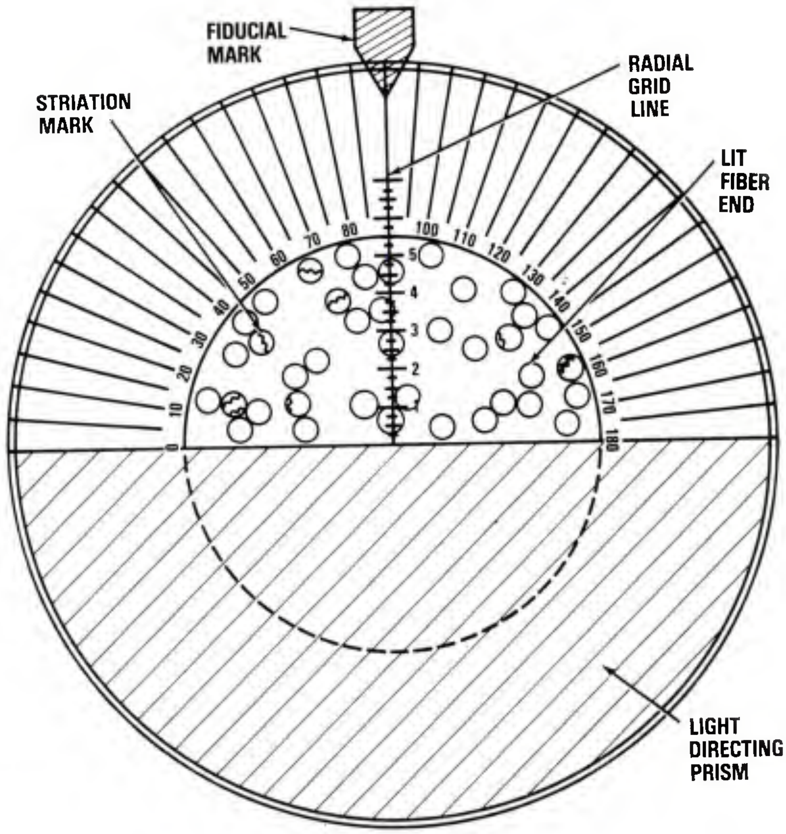

Figure 6. Eyepiece reticle pattern superimposed on representation of fiber optic seal fingerprint.

The second reticle fits closely to the front face of the fiber optic seal in the hand-held viewer. This reticle consists of two line segments along the diameter of the reticle disk as shown in figure 7. The two line segments have a ratio of 10 to 1 with the thicker segment being between 1.5 and 2 times the nominal fiber diameter.

Both reticles can be rotated in the viewer by external control. The eyepiece reticle is rotated by turning the top part of the eyepiece lens holder. The line segment reticle is rotated by the knurled reticle mount ring that protrudes through two sides of the hand-held viewer block as shown in figure 5.

The eyepiece reticle can be used to locate the position of any of the lit fibers in the fiber optic seal fingerprint in an r, θ coordinate system. The r coordinate of a lit fiber is determined by its position under the radial grid line of the reticle pattern.

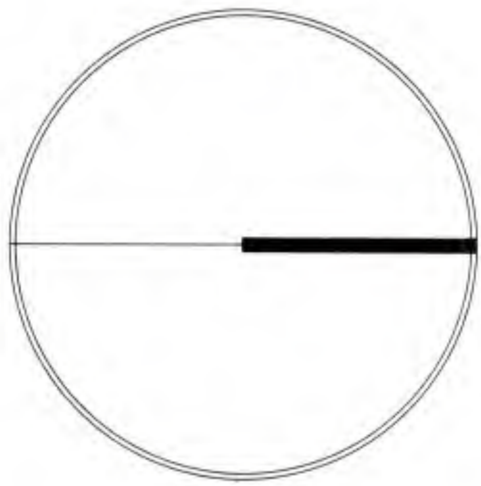

Figure 7. Line segment reticle.

The θ coordinate is determined by the angular position of the radial grid line as indicated by the reading under the stationary fiducial mark. The stationary fiducial mark appears near the periphery of the reticle pattern as shown in figure 6.

Seal identification is accomplished by using both the eyepiece and line reticles in the following scheme devised by Lorin R. Stieff, formerly with ACDA. The location (r, θ coordinates) of a number of the lit fiber ends is specified by using the eyepiece reticle. Striation marks on any of the lit fiber ends should also be indicated along with the coordinates to aid in seal identification. Using only the eyepiece reticles for seal identification might require the location of many lit fiber ends to insure positive seal identification. However, using the features of the second reticle (line segment reticle) in conjunction with the eyepiece reticle greatly simplifies seal identification.

The line segment reticle rotates in a plane parallel to and slightly in front of the face of the fiber optic seal. When the broader line segment rotates under the light directing prism, it blocks light from entering some of the fibers. Due to the random distribution of the intermixed fibers in the seal, various fibers blink off and on as the line reticle is rotated. This feature can be utilized for seal identification by specifying certain lit fiber ends in the seal's fingerprint that blink off upon reticle line rotation. These fibers are then located in r, θ coordinates by the eyepiece reticle. Next, the line segment reticle is rotated until the specified lit fiber appears the darkest. The angular position of the line segment reticle at which this maximum extinction of the lit fiber occurs is then noted. The narrower line segment on the reticle is used to indicate the angular position of the broader line segment. The angular position of the narrow line segment is determined by reading its location with respect to the superimposed angular markings on the eyepiece reticle.

The advantages of using both reticles is that the seal can be identified, verified, and checked for integrity by specifying the coordinates, striations, and extinction angles of only a few lit fibers in the seal's fingerprint. Furthermore, the extinction angles do not have to be specified precisely, but only as falling within some spread of an angle such as ±5 deg.

Another important feature of the rotatable line segment reticle is that it allows the seal to be examined to determine whether any masks or films have been used to simulate its fingerprint. If the fingerprint is simulated by a mask or any other means than a continuous looped fiber optic bundle, the lit fiber ends will not blink on and off as the line reticle is rotated.

3. ENVIRONMENTAL TESTS

A preliminary set of environmental tests was conducted on the fiber optic seals and the inspection equipment as described below.

3.1 Temperature Test on Fiber Optic Seals

Plastic fiber optic seals having the compact collar shown in figure 3(a) and the improved collar in figure 3(c) were subjected to temperatures from +66 to -57 C (+150 to -70 F). The seals were placed for 1-hr intervals in a test chamber at each of the following temperatures: 66, 49, 23, 0, -18, -40, and -57 C. Photographs were taken of the seals at the beginning of the test at room temperature and after each hour-long exposure in the test chamber set at those temperatures. No noticeable change occurred in the seal fingerprints upon being exposed to temperatures ranging from +66 to -57 C.

3.2 Temperature Test on Complete Fiber Optic Seal System

A complete fiber optic seal inspection system (fig. 2) consisting of a camera, a hand-held viewer, and a fiber optic seal was placed into a cold chamber at -40 C for 15 min. A photograph taken within 30 s after removal of the system from the chamber showed poor resolution on the film. Also, the shutter did not operate properly. Another photograph taken after 1 min showed overexposure of fibers due to the open shutter. After 5 min, normal pictures were obtained. The batteries for the light source in the hand-held viewer functioned properly when the system was taken out of the cold chamber. However, when the hand-held viewer, was subjected to the -40 C temperature environment for 1/2 hr, the batteries no longer functioned. After the viewer had thawed for 10 min at room temperature (23 C), the batteries sufficiently recovered to again enable proper viewing and photographing of the seals.

3.3 Temperature Test on Crimped and Twisted Seal

A plastic fiber optic seal was placed in a cold chamber for 1 hr at -57 C and photographed. The seal was then placed in the chamber for another hour at -57 C. Immediately after the seal was removed from the chamber, its bundle was crimped while its sheathing was frozen rigid. About 3 min later, after the bundle had softened, a fingerprint of the seal was photographed. No changes were noticeable in the fingerprint.

Next, the seal was placed back into the cold chamber for another hour at -57 C. The seal was taken out and immediately crimped, twisted, and photographed before the bundle softened. Again, no changes were noticeable in the fingerprint.

3.4 Water Submersion Test

A plastic fiber optic seal was placed in a beaker of tap water at room temperature for 1 and 24 hr. The seal's fingerprints were photographed before the test and after the 1- and 24-hr submersions. The photographs showed that after submersion of the seal in water, no noticeable change in the seal's fingerprints occurred.

4. CONCLUSIONS

The fiber optic seal development program has been directed to providing a sealing system that is simple to assemble and inspect in the field. The current seals with the improved collar as shown in figure 3(c) have further simplified the task of installing them. The collar allows easy insertion of the fibers and allows holding the fiber bundle close to the intermixed fiber ends during assembly, thus insuring that the fibers remain intermixed.

Seal inspection with the current equipment is normally performed by taking positive/negative photographs of the seal's fingerprints. When many seals need to be inspected, the filing of the photographs and the necessity of carrying photographs to the inspection site may be impractical. The reticle pattern projection method of seal identification circumvents the need of taking photographs. However, with the prototype system described here, it takes considerably longer to make a reliable visual identification and an intergrity check of a seal than to photograph the seal's fingerprints and to match positive/negative overlays.

The seal identification time and effort could conceivably be greatly reduced by having a computer recognize the seal pattern. In the reticle pattern projection method of seal identification, the seal's fingerprints are identified by (1) the position coordinates of lit fiber ends, (2) striation marks on the fiber ends, and (3) the position of a line reticle or mask at which certain lit fibers in the field of view become extinguished. These same characteristics of the fingerprints might be suitable inputs for the computer algorithms needed for pattern recognition. In such a system, information on the seal's pattern could be stored in the computer memory for comparison with subsequent seal checks with an optical reader and decoder.

ACKNOWLEDGEMENT

The author thanks Lorin Stieff of Fiber-Lock Corp., formerly with ACDA, for his enthusiastic direction during this phase of system development.

APPENDIX A.--OPERATING PROCEDURE FOR FIBER OPTIC SEAL ASSEMBLY AND INSPECTION KIT

FIGURES

A-1. DETAILED SEAL ASSEMBLY

The following procedures refer to the fiber optic seal assembly and inspection kit shown in figure A-1 and developed for the U.S. Arms Control and Disarmament Agency (ACDA) in FY76.

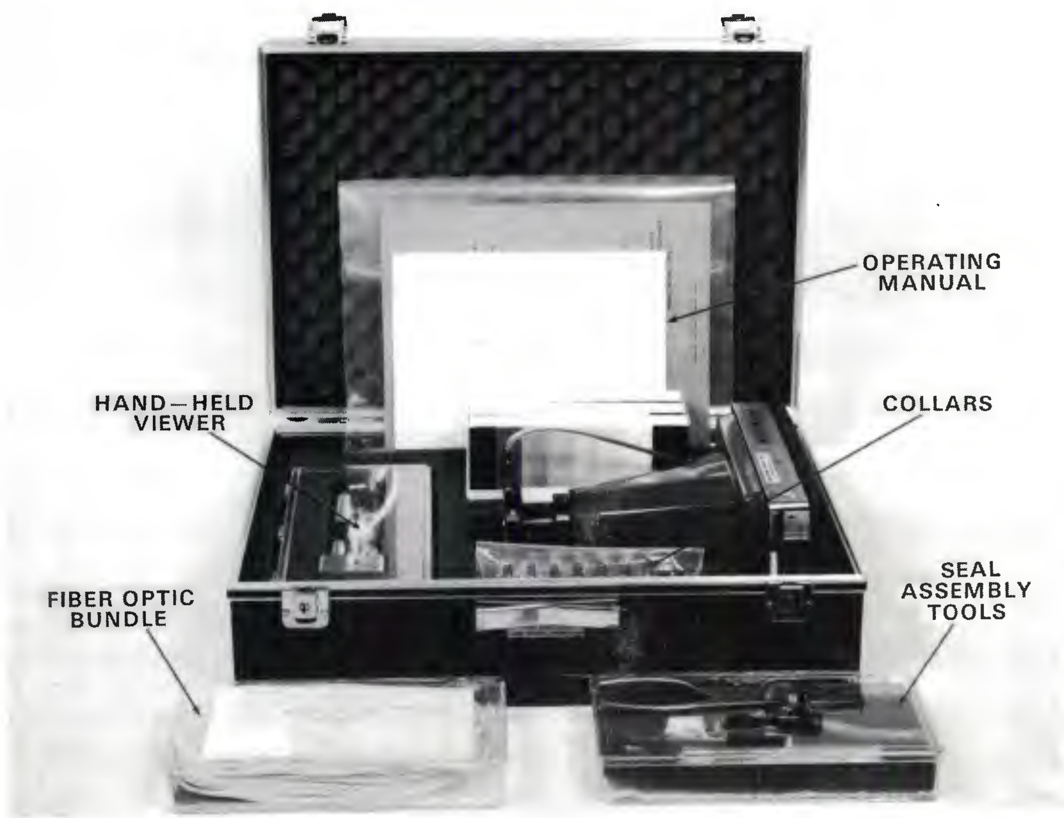

Figure A-1. Fiber optic seal assembly and inspection kit.

Seal assembly requires looping a plastic fiber optic bundle around or through the item or container to be sealed. The two ends of the bundle are then fastened in a collar containing a small flexible rubber filler ring (fig. A-2). As the collar end cap is tightened against the main body of the collar, the flexible filler ring compresses against the fibers. Terminating the fibers at the front face of the collar with a knife completes the assembly of the fiber optic seal. The following steps indicate in detail the recommended procedure for field installation of the seals:

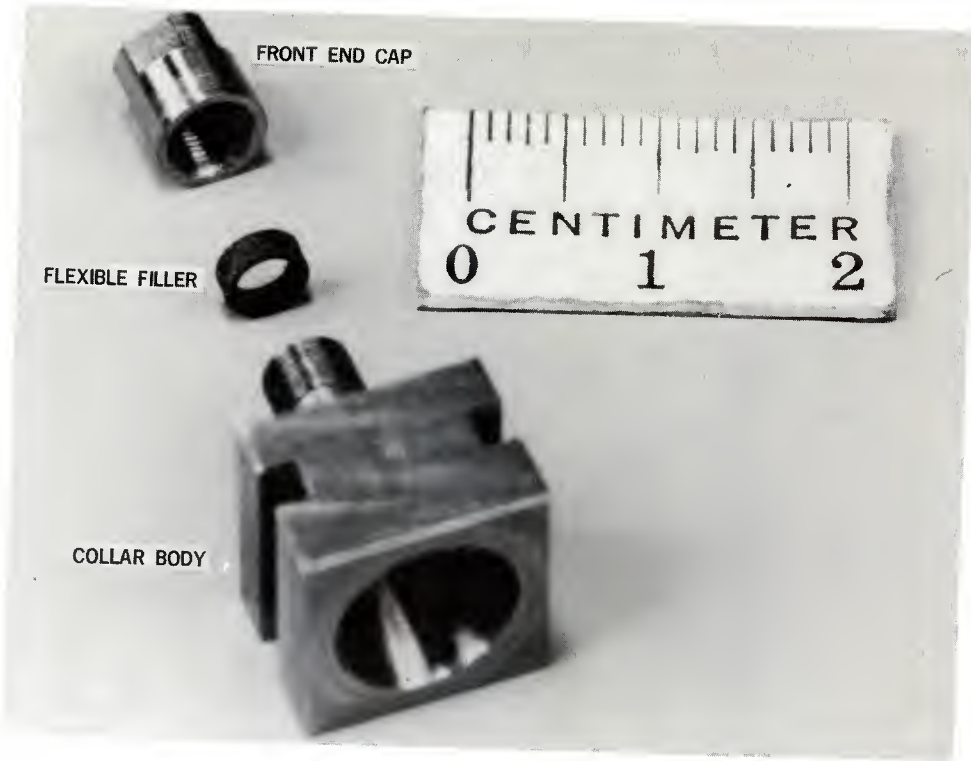

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Figure A-2. Fiber optic seal collar components.

a. Determine the length of the plastic fiber optic bundle required to secure the item or container in its field location. Loop the fiber bundle around or through the item to be sealed, leaving just enough slack for easy assembly and inspection of the seal. Avoid excessive slack, and keep the fiber bundle length to a minimum. Cut the plastic fiber optic bundle to the desired length with cutters.

b. Remove about 2 cm (0.75 in.) of polyvinyl sheathing at each end of the fiber optic bundle. For bundle lengths under 60 cm (2 ft), remove the sheathing by pushing the fibers slightly at one end of the bundle until they can be held at the other end. Use the 2 mm-diameter wooden dowel pin provided with the kit to push the fibers in the sheathing. Next, pull the fibers at the opposite end of the bundle until 4 cm (1.5 in.) of fibers is exposed. Using the wire cutters, snip off the 4 cm section of sheathing that has no fibers under it. Push the fibers back into the sheathing until an equal length of fibers is protruding from both ends of the fiber bundle. For fiber bundles greater than 60 cm or as an alternative to the procedure just described, remove the polyvinyl sheathing by cutting about 2 cm of sheathing from each end of the bundle with a knife, wire strippers, or wire cutters. However, be careful not to cut the plastic fibers under the sheathing.

You may do step b before going to the field site by bringing along pretrimmed fiber bundles of various lengths. The maximum length of plastic fiber optic bundle provided with the kit is 3.05 m (10 ft).

c. Place the fiber bundle in position at its field location. Loop the two ends of the fiber bundle together, and intermix the fiber ends as shown in figure A-3(a).

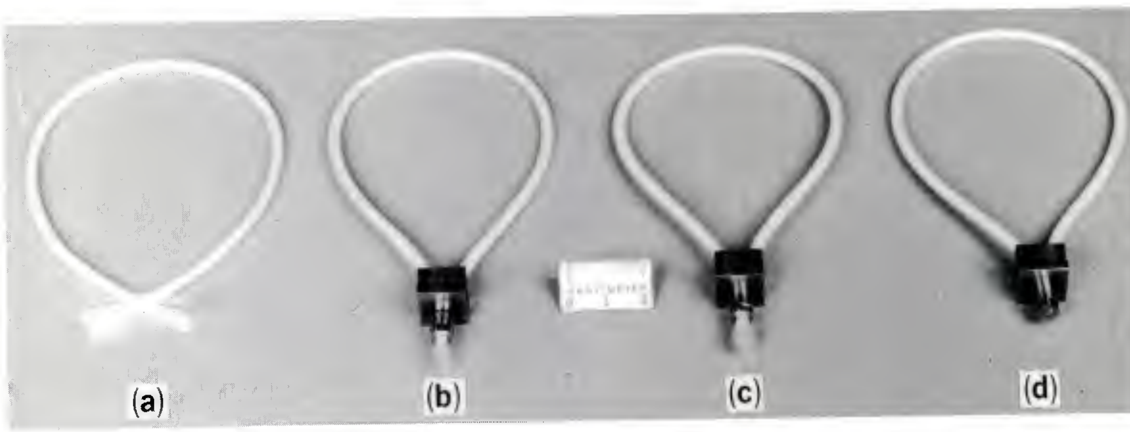

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Figure A-3. Fiber optic seal assembly procedure: (a) intermix fibers, (b) insert fibers into collar, (c) tighten front end cap, and (d) terminate fibers flush with front face.

d. Remove a seal collar from the kit, and screw the front end cap down with your fingers. Stop turning the cap before the flexible filler ring begins to compress. Twist the intermixed fibers slightly and insert them into the rear of the collar. Push the fibers through the collar until the sheathing from both ends of the fiber bundle rests against the surface of the conical hole within the collar. Note that the plastic fibers protrude through the front of the collar as shown in figure A-3(b).

e. Hold the collar with the plyers provided with the kit, and place the wrench on the front end cap. The wrench has an opening that allows it to be slipped sideways around the fibers onto the collar. Tighten the front cap with the wrench until it rests firmly on the shoulder of the main collar body. Doing so insures that the flexible filler ring will be compressed properly and that the seal will be in focus under the hand-held viewer (fig. A-3c).

f. Place a strip of sticking tape around the fibers protruding through the front of the collar to prevent them from being scattered when you cut them off. Examine the small knife supplied with the kit, and make certain that the blade is sharp. (Emery cloth and spare blades are provided with the kit.) Cut the fibers flush with the front face of the collar. Run the knife blade across the fibers again to insure that you cut off all the fibers in the same plane.

No further end polishing or preparation is required. This completes the assembly of the plastic fiber optic seal (fig. A-3d).

g. After assembling and installing the seal in its field location, log the identification number engraved on one of the side facets of the collar.

A-2. SEAL INSPECTION

A-2.1 Viewing Fiber Optic Seal Fingerprints

A 30-times enlargement of the fiber ends forming the unique fingerprints of the seals can be seen through the hand-held viewer. The following steps are recommended for viewing the fiber optic seal fingerprints:

a. Remove the hand-held viewer from the kit (fig. A1). Press the viewer penlight on momentarily, and observe whether a bright light spot appears in the seal mount block opening. If the light appears dim, replace the batteries. If the light does not turn on, check the batteries or the No. 222 lamp bulb. (Spare batteries and bulbs are supplied with the kit.) Also, check that the spiral spring is engaged with the lamp bulb thread and that it is in contact with the viewer block housing when the lamp is in position.

b. Check the hand-held viewer by positioning the reference seal supplied with the kit onto the seal mounting block on the hand-held viewer. Position the seal by placing the two small locator pins on the seal mounting block into the two holes in the seal collar shoulder. (These holes are located 180 deg about the collar axis and allow two precise orientations of the seals.) Use the orientation indicator dot on one of the side surfaces of the seal collar to distinguish one orientation from the other. (When the dot on the seal collar is next to the dot on the seal mounting block, the seal is in the "dotted" orientation as distinguished from the "nondotted" orientation.) Designate the dotted orientation by placing a dot after the seal identification number when you refer to the seal fingerprints.

c. Slide the spring clip on the mounting block over the rear surface of the collar to hold the seal in place.

d. Turn the penlight knob switch on (clockwise), and view the reference seal. Turn the switch off (counterclockwise) when you are not viewing or photographing the seal.

e. Loosen the focus control knob (located on the viewer tube immediately above the viewer block) by turning the focus control lock ring clockwise while looking through the viewer. Turn the focus control knob until the reference seal fingerprint appears in sharp focus through the viewer. Lock the focus control knob by holding it in position with the thumb of one hand while turning the focus control lock ring against it with your other hand.

f. Compare the views seen through the hand-held viewer with the positive prints of the reference seal fingerprints provided with the kit. (If the views agree with the fingerprints, then the hand-held viewer is suitable for viewing any other seal that is being installed or inspected. The field of view seen through the hand-held viewer is slightly greater than the field of view of the viewer-camera arrangement. Therefore, some fibers that appear along the periphery through the viewer may not appear on the photographs. However, everything appearing on the photographs must be identifiable through the viewer to insure that the integrity of the seal has been maintained and that the viewer is functioning properly.) If you are uncertain as to whether the viewer is showing the same view for the reference seal as shown in the photographs, take another positive/negative photograph of the reference seal. Use the procedures for photographing the seals described in section A-2.2 and the procedures for identifying and verifying the integrity of the seals described in section A-3.

A-2.2 <u>Photographing Fiber Optic Seal Fingerprints</u>

The following procedure is recommended for photographing the fiber optic seal fingerprints:

a. Remove the camera assembly with the attached cable release from the carrying case (fig. A-1).

b. Set the camera shutter speed lever on B.

c. Place a Polaroid Type 105 P/N film pack into the camera. (Follow the loading instructions included with the film.)

d. Place the hand-held viewer onto the front of the camera. Slide the two pins on the ring surrounding the eyepiece of the viewer into the slots on the mounting tube on the camera. (The two pins fit in the slots in only one orientation of the viewer. In this orientation, the penlight is on top when the camera film departs from the left.) Press the pins into the mounting tube slots as far as they will go, and then twist the hand-held viewer clockwise onto the camera. Make sure that the rubber O-ring at the front of the eyepiece holds the viewer firmly onto the camera.

e. Hold the camera so that you can pull the film tabs from the right side.

f. Attach the seal onto the hand-held viewer following procedure b of section A-2.1. (As an alternative procedure to steps d to f, attach the viewer to the seal prior to attaching the viewer to the camera. This method subjects the seal to the possibility of greater stress than when the seal is placed onto the viewer-camera combination just before the photograph is taken and then is removed immediately thereafter.)

g. Hold the seal-viewer-camera assembly with one hand, and turn on the penlight knob switch (clockwise) with the other hand.

h. Press the camera shutter cable release to open the shutter. For the Polaroid Type 105 P/N film, press the cable release for 30 s. If the batteries are not at peak, press the release for 40 s to 1 min.

i. Turn off the penlight knob switch (counterclockwise) immediately after the shutter has closed.

j. Detach the viewer-camera assembly from the seal, and then pull out the tab and film from the camera as explained in the instructions included with the film.

k. Write the seal identification number and orientation (dotted or nondotted) on the positive and negative prints.

l. Coat the positive print with the coater included with the film within 5 min after the print is taken. (Besides preventing fading of the positive print, the coating enchances the print contrast for the Type 105 film.)

m. Remove the negative print from the field site and transport it in a container to avoid scratching.

n. Wash both sides of the negative print in cold water for at least 30 s. Then hang up the negative to dry. (This is the minimum care that is needed to obtain useful negative prints for overlays.) See the instructions accompanying the Polaroid Type 105 P/N film for additional development procedures that can be used if time and facilities permit.

o. Before leaving the test site, remove all film wrappings and debris formed in photographing the seals.

A-3. SEAL IDENTIFICATION, VERIFICATION, AND INTEGRITY CHECK

Seal identification and an integrity check indicating whether the seal has been tampered with since its installation can be accomplished by either visual-photographic comparison or photographic overlay. In visual-photographic comparison, the seal is observed through the hand-held viewer. This view of the seal is then compared with the positive print taken when the seal was installed. Visual-photographic comparison requires looking alternately through the viewer and at the print a number of times until it can be ascertained whether the patterns are the same.

In photographic overlay, positive prints are taken of the seal fingerprints at the time of inspection. These prints are then overlaid with the negative prints taken when the seal was installed. If a negative print overlay matches and entirely blocks out a positive fingerprint, then the seal has not been tampered with. Because this method relies less on the judgment of the observers as to whether the fingerprint patterns have remained the same, photographic overlay is superior to visual-photographic comparison.

The photographic overlay method for seal identification and integrity verification is as follows:

a. Check the integrity of the hand-held viewer using the procedure of section A-2.1.

b. Photograph the seal fingerprints using the procedure of section A-2.2. The Polaroid Type 105 P/N film (ASA 75) may be substituted with Polaroid Type 107 film (ASA 3000) since only positive prints are required. When using this film, set the exposure time from 1/2 to 1 s, depending on the lamp brightness.

c. Overlay the positive prints with the corresponding negative prints taken of the seal fingerprints upon installation.

d. Determine whether the negative print overlay matches and entirely blocks out the positive fingerprint. For a nontampered seal, the overlay will match precisely with the positive print.

To verify the integrity of the seal, the seal bundle should also be examined visually for any discontinuities or irregularities. The exposed fiber ends at the front of the seal collar should be checked by sweeping a penlight across the fibers. Different fibers should light up as the light is swept across the fibers, indicating that the seal consists of a bundle of continuous intermixed fibers. This method will reveal if any mask simulating a fiber pattern has been used. (For kits equipped with a line reticle as described in section 2 of the main body of the report, mask or film simulation of the fibers can be revealed as the operator looks at the seal through the hand-held viewer while rotating the reticle.)

A-4. SEAL REMOVAL AND DISPOSAL

The following procedure is recommended for seal removal and disposal:

a. Remove the seal from its field location by clipping the plastic fiber bundle with the wire cutters about 2 cm behind the collar on one side of the bundle loop. Use sticking tape to secure the polyvinyl sheathing sections onto the collar.

b. Visually inspect the fiber bundle soon after its removal. Shine light into the ends of the fibers, and check for the presence of any masks or other pattern simulators.

c. Place the collar and fiber optic bundle pieces in an envelope for further examination in the laboratory.

d. To dispose of the fiber optic seal, loosen the front cap on the seal collar and pull all the fibers out. Clip the longer of the two sections of fiber bundle at both ends. (This section of the fiber optic bundle and the collar can be used over again to form other seals.)

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